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AN ANALYSIS OF FACTORS ASSOCIATED WITH INSECT LOSS ON ONE-ACRE PLOTS IN EASTERN OREGON AND WASHINGTON

by

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AN ANALYSIS OF FACTORS ASSOCIATED WITH INSECT LOSS ON ONE-ACRE PLOTS IN EASTERN OREGON AND WASHINGTON

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INTRODUCTION

One of the greatest limiting factors to the successful sustained yield management of ponderosa pine is the hazard of serious beetle depredations to mature and over-mature stands of this tree. The gross loss of ponderosa pine timber from bark beetle attack has been 16 times greater than the loss from fire during the past two decades in eastern Oregon and Washington. Obviously, a drain due to insect attack of more than three quarters of a billion board feet per year, which in itself more than offsets growth, makes the possibility of balancing growth with drain rather remote.

One of the outstanding characteristics of these beetle-caused losses has been their uneven distribution. Some areas have lost over fifty percent of their merchantable volume, while others only a few miles away, show only minor losses and have been putting on net growth even during years of generally adverse climatic conditions.

An understanding of the factors which cause these loss differences and an ability to recognize the hazard of different areas would be an important help in the solution of the beetle problem. It would permit timber owners and managers to sell or cut high risk areas ahead of those relatively immune to beetle attack. It would make possible the planning of general cutting policies with the beetle hazard factor in mind and provide a basis for determining the desirable amount of cut. It would also assist in the formulation of insect control plans in order to provide the greatest protection from further beetle depredations.

This problem of determining what forest conditions constitute or influence the hazard of bark beetle attack in the ponderosa pine forests of California, Oregon and Washington and the relative importance of these hazard factors has been given the attention of forest entomologists at the Portland and Berkeley laboratories for the past several years.

The importance of this problem was recognized eighteen years ago when Craighead [1] reported the tentative conclusions of entomologists dealing with the western pine beetle problem. At that time it was recognized that losses were associated with poor site and were heaviest in stands of mature, decadent and slow-growing trees. Person [2] brought out the fact in 1928 that losses were associated with open, pure stands of pine along ridges or any exposed sites; and that rapidly growing pines in dense stands, especially in mixtures on north slopes or in low moist situations were least attractive to the western pine beetle.

A decade later, Miller, Salman and Johnson [7] divided the ponderosa pine stands in northeastern California into five hazard zones which were set up on a more or less empirical basis using knowledge gained from general observations and studies started by Salman and Johnson [3] in 1936. This beetle hazard inventory was based on the assumption that two factors, (1) past loss as indicated by snag counts and (2) the percentage of risk trees in the stand, were the criteria which indicated future loss. These two factors were given equal weight in arriving at an estimate of future loss.

In 1939, Keen [4] made a multiple correlation analysis of data for ten years of loss on 25 full section sample plots in the Klamath Basin. Quoting Keen, "This showed that the gross insect loss which occurred on these plots during the ten-year period 1921-1930 was correlated with site index, volume per acre, growth rate and reduction in growth during the period 1921-1930 from the previous average. A regression equation was developed which combined these factors, and with this fifty-one percent of the variance in current loss was explained. Of these factors, growth reduction was the most important and the only one to show significance in the partial correlation tests."

Later in the same year, Keen [5] discussed a method for determining area hazard on an empirical basis. In this he recognized the following ten factors as possibly having some influence on hazard: (1) Life zone, (2) elevation, (3) temperature, (4) past losses, (5) growth rate, (6) forest type, (7) site quality, (8) stand volume, (9) stand structure, and (10) fire history. Five of these, numbers 2, 4, 6, 7, and 8 above, were combined on an equal basis by a system of transparent map overlays to arrive at an estimate of future hazard. It was found that the final hazard map derived in this manner required some modification by personal judgment of an entomologist familiar with the area in question. On this basis, hazard maps were prepared for the pine stands in the Klamath [6] and Deschutes subregions.

All of this work on hazard zonation was of immediate practical value, still, most of it was empirical in character and none of it had been tested as to its ability to predict future loss. Keen and Grant [8], wishing to determine what factors actually are indicative of future loss and the importance of each, made a second series of multiple correlation analyses in 1941. In making these analyses, two different sets of data were used. In the first analysis, they used past loss on twenty-five 640-acre sample plots in the Klamath Basin and a stand inventory of these plots in 1931 to predict the future loss which occurred from 1931-1940. This showed a highly significant correlation between future loss and past loss and a highly significant negative correlation between future loss and susceptible volume per acre, but no significance to the correlation between future loss and past growth reduction.

The next two analyses were based on data from 114 320-acre plots scattered throughout eastern Oregon and Washington, on which a stand inventory and snag count had been made in 1937. These data were used to predict future loss from 1937-1940. In this study it was found that volume per acre and 1936 growth reduction were significantly associated with future loss and that past loss was highly so. The first two were about equally correlated with future loss, but past loss was more closely associated and was responsible for half of the explained variation of forty-one percent.

Thus, of the ten hazard factors expressed by Keen 5/, three ie., past loss, growth reduction and stand volume are significantly correlated with future loss; and one, stand structure, at least percent of susceptible volume, is not. Of the remaining six factors, life zone, elevation, temperature, and forest type are pretty well interrelated so that any one would be a fair expression of life zone. Site quality, although somewhat related to life zone, is also independent to some degree; and fire history is entirely so.

PRESENT STUDY

It was with these untested factors in mind, that Keen devised the one-acre plot study. He had found that the large 640- and 320-acre plots represented diversities in elevation, site quality and fire history and were therefore not satisfactory for the purposes of analyzing these factors. Hence, the small one-acre plots were for the purpose of representing a uniform sample of hazard conditions. A few of these plots were established in 1938, but the bulk of the data was secured in 1939.

It is important to note the date when this study was made, otherwise this report will appear to be a retrogression in the field of hazard factor analysis. Actually, a report of this study should have followed Keen's analysis 4/ in 1939. This would have completed the picture of associating the ten hazard factors with current loss. Hence, it must be realized that this study was designed during the period when the relationship of hazard factors to current beetle loss was being determined without any attempt to test these factors in predicting future loss.

Method of one-acre plot survey.

In order to make a statistical analysis of the factors underlying bark beetle losses, it was planned to make intensive cruises of a large series of one-acre rectangular sample plots distributed at random through the ponderosa pine type of eastern Oregon and Washington.

The exact location and distribution of these plots was left to the judgment of the crew leader with a few reservations. Each day's work was restricted to an elevational zone so as to sample low, medium and high elevations. The strip to be run was selected on a type map before going into the field and plots along this strip were not closer than five chains apart. Plots were located in mature timber types to include Forest Survey types 5½, 20, 20 A, 20 B, 20.5, 21 and 27, and were to represent as wide a range in losses and as many different timber stand conditions as possible. Each plot sampled one uniform condition, such as heavy brush or light brush, heavy timber stand or light timber stand, uniform site, etc.

These plots were laid out with a chain and the corners marked. Tree diameters were taken with a diameter tape, except some below 30 inches which were measured with a Biltmore rule. Tree heights were taken with an Abney level.

On these plots, all living trees ten inches and over in d.b.h. (O.B.) were tallied by diameters and the heights recorded. All ponderosa pines recorded were given a Keen tree class and other species were indicated by the proper species symbol. All standing snags and down bug-killed trees ten inches d.b.h. and over were recorded by diameters and heights. Windfalls ten inches and over and solid enough to hold the cruiser's weight were noted by diameters and species. High stumps cut in beetle control and low stumps cut in logging were tallied by group and diameter. Poles 4-9 inches d.b.h. were tallied by species. Reproduction was recorded by average height and percent of ground covered, and the percent of ground covered by brush was also noted. Elevation, site, presence, or absence of fire injury, and any reason to explain heavy or light bark beetle losses were recorded. Finally, increment cores were taken from eight dominant or typical trees on or closely adjacent to the plot and which reflected the conditions of that plot.

These plots were established and the data recorded by the survey crews employed for the annual fall bark beetle surveys. The one-acre plot work was done at the conclusion of each day's survey so that a few sample plots were taken each day. In all, records were available for this analysis from 139 one-acre plots scattered throughout eastern Oregon and Washington.

ANALYSIS OF DATA

The data representing these 139 plots required a considerable amount of summarizing before they were finally ready for analysis. Of this work, the measurement of the cores was by far the most time consuming. This was done by Mr. Jack Huber, a temporary employee of the Portland laboratory, who had had an extensive experience in this work. Appreciation is also expressed to Mr. T. J. Orr, Jr., of the Klamath Falls Unit of the Weyerhaeuser Timber Company who hired a computor and directed him in the correlation work.

When the data were finally summarized, the following variables were used for the simple correlations:

Dependent:

x - past loss in percent of stand. This is the mean annual loss for a ten-year period (1929-1938) determined from snag and stump counts. (It is to be noted that standing snags are not positively ten years' loss and might represent a period range from say six to fifteen years.)

Independent:

a - elevation. Actual elevation was divided by 1000 to eliminate large figures in the calculations.

b - forest type in percent mixture by basal area. This is the percent of total basal area comprised by species other than ponderosa pine.

c - site. Actual 1, 2, 3, etc. was used.

d - stems per acre. An expression of competition using total stems for all species including poles, snags and stumps.

e - basal area per acre. Another expression of competition using total basal area of all species as in "d."

f - brush. An expression of competition using the percent of ground covered by brush.

g - reproduction. An expression of competition using the percent of ground covered by reproduction multiplied by its average height.

h - fire injury. As recorded on these plots, the mere presence or absence of fire injury was noted. No difference in degree could be ascertained and the records of this factor are not good for the purpose of this analysis. The numeral two was used if fire injury was present and one if absent.

i - age. Expressed as the sum of Keen age classes.

j - vigor. Expressed as the sum of Keen vigor classes using - A = 1, B = 2, C = 3, and D = 4.

k - age and vigor. Expressed as the sum of mortality ratios for Keen tree classes.

l - percent susceptible volume. Expressed as the percent of stand in susceptible volume which included all C, D, and 4B trees.

m - susceptible volume. Expressed as the susceptible volume per acre.

Independents:

n - growth rate. Percent of normal growth secured by dividing the mean growth for the period 1929-1938 by the mean growth for the period 1880-1929.

o - susceptible volume plus snags. This was an attempt to reconstruct the original stand of 1929. Snags were considered to have been susceptible volume and were added to the green susceptible volume in arriving at the percent of stand in susceptible volume.

p - stand volume. An expression of competition using total volume per acre.

The simple correlation coefficients (r) are recorded in the following tabulation:

x - (current loss) correlates with	r	Significance *
a - (elevation)	- 0.004	none
b - (type percent basal area)	.028	none
c - (site)	.011	none
d - (stems per acre)	.001	none
e - (basal area per acre)	- 0.050	none
f - (brush)	.188	significant
g - (reproduction)	.370	high
h - (fire injury)	.058	none
i - (age)	- 0.113	none
j - (vigor)	- 0.179	significant
k - (age and vigor)	- 0.060	none
l - (percent susceptible volume)	.160	nearly
m - (susceptible volume/acre)	- 0.149	nearly
n - (growth)	.012	none
o - (percent susceptible volume plus snags)	.474	high
p - (volume per acre)	- 0.298	high

* Significant values of r: 0.174 least significant
0.228 highly significant

The correlation coefficients in the above tabulation indicate the possibility of some interesting deductions. At the top of the table, it is evident that elevation, type and site were not significantly correlated with current loss in this problem. However, we know without experimental proof that gross insect losses vary according to life zones, and since these factors are more or less measurements of life zone, this leads one to suspect that some weakness in sampling caused the lack of correlation. An examination of the original data shows, (1) that the elevational range represented varied between 3000 and 5600 feet with the bulk of the plots at about 4000, (2) that 91 percent

of the plots showed less than 30 percent mixture and that 56 percent of the plots were taken in pure pine so that the percentage mixture in the stand was zero for more than half of the plots, and (3) that 55 percent of the plots were taken on site IV and 32 percent on site III, leaving 11 percent on site V and two percent on site II. These extreme inequalities in representation give ample reason for the lack of significant correlation shown by these three factors. Whether or not this is the true cause cannot be shown, but one can strongly suspect that this is the reason.

Stand density, both in total stems and basal area, showed no significant correlation with current loss. It was anticipated that the total number of stems on the plot would not be important because the size of the stems would cause a considerable variation. It was surprising, however, that total basal area showed such a low correlation coefficient because volume per acre (variable "p") in this study showed a highly significant correlation with current loss, and Keen [4/ 8/] found volume per acre to be significantly correlated with both current and future loss. It would appear that basal area was not a satisfactory measure of stocking in this study.

Current loss was significantly correlated with the amount of brush, and showed a highly significant correlation coefficient with reproduction. The question naturally arises whether the brush and reproduction occurred before or after the insect loss. Although no age records were made, judging from its height, most of the reproduction had become established long before the loss recorded in this study had occurred. However, since Keen [8/] found the strongest correlation between future loss and past loss, it is probably true that the reproduction and brush began coming into these plots as the stand gradually thinned out because of insect attack. This gives strong indication that brush and reproduction, particularly the latter, would show a highly significant correlation with future loss.

As pointed out, the method of recording fire injury was not satisfactory for the purpose of this study, so that it is not surprising that no relationship between fire and current loss was shown in this problem. More information concerning the effects of fire is needed, so that definite measurable characters will be available for studies of this type.

Several factors were available in the one-acre plot data to test the relationship of stand structure with current loss. Of these, age showed a tendency toward a significant negative correlation coefficient and vigor was also negative and just above the level of least significance. When the two were combined, however, and weighed according to the known Keen tree class mortality ratios, the correlation with current loss showed no significance. This would indicate, (1) that of these factors, current loss correlates best with current health as judged by tree vigor, (2) that to some degree current loss depends on age, probably because the latter influences current health, and

(3) that current loss is not dependent on the average stand mortality ratio probably because there was a compensating action between age and vigor in certain types of stands and because these long-term ratios were not applicable to the short ten-year term of mortality.

The remaining stand structure factors tested in this problem were measurements of the susceptible volume. Both the percent of susceptible volume in the stand and the susceptible volume per acre approached significance when correlated with current loss. Susceptible volume per acre showed a negative relationship similar to Keen's 4/ 8/ simple correlation coefficients, although his were of much higher significance. In other words, he found that, "losses did not occur where the greatest volume of susceptible material occurred, because high volume of susceptible trees was associated with high stand volume, which in turn reflected good site. Poor sites had low stand volume and hence low volume per acre of susceptible material." On the other hand, the percent of susceptible volume showed a positive relationship with the percent of stand killed because both loss and susceptible volume were reduced by a common denominator which brings out the relationship pointed out by Salman and Johnson. 3/

Although the percent of green susceptible volume plus snag volume in the stand showed a highly significant correlation coefficient with current loss, it is obvious that the correlation is not legitimate because the dependent variable has been added to susceptible volume and correlated with itself. This naturally would be highly significant, since susceptible volume alone approaches significance.

The final factor tested in this problem, growth reduction during the ten-year period of current loss, was not significantly correlated with current loss. Keen 4/ found this correlation highly significant in his first study, and in his later work 8/, growth reduction during the year immediately preceding the period of loss proved important. No explanation can be offered as to why there was no significant correlation in this problem unless the trees from which the cores were taken were not representative of growth conditions on the plots.

Thus, the correlation between independent variables showed the following significant relationships with current loss in this problem:

factor	significance	relationship
Brush	significant	positive
Reproduction	highly significant	positive
Tree vigor	significant	negative
Sus. volume plus snags	highly significant	positive
Volume per acre	highly significant	negative

Of these, brush was eliminated because of its similarity to reproduction, and susceptible volume plus snags was dropped because of its illegitimacy. Then the three remaining independent variables were combined with the

dependent in a multiple regression. The coefficient of multiple correlation was 0.456 and was of high significance (0.260 least significant value; 0.307 highly significant value) which shows that approximately 21 percent of the variability in current loss was explained by these three factors. The unexplained source of variation in this study is shown in the following table:

Source of Variation	Degrees of freedom	Sums of squares	Mean square	Standard deviation
Due to regression	4	49.96	12.49	
Not accounted for	135	190.22	1.40	1.18
Total	139	240.18	1.72	1.31

The importance or weight of these three independent variables in explaining current loss is shown in the following comparison of standard regression coefficients:

Variable	Standard regression coefficient	"t" value *	Significance	Weight
Reproduction	0.2965	3.655	high	43%
Tree vigor	0.1461	1.799	none	22%
Volume/acre	0.2423	3.040	high	35%
Total	0.6849			100%

* 5% - 1.979
1% - 2.610

It is obvious that having failed to explain 79 percent of the total variation, the three factors used in this analysis do not give a very satisfactory measure of current loss. Of the explained variation, the factor of reproduction accounts for 43 percent and stand volume for 35 percent, while tree vigor is least important of the three.

DISCUSSION

Of the sixteen factors considered in this study, the variable of ground cover (brush and reproduction) proved to be most significantly correlated with current loss. This is the one new factor which this study adds to those already known to influence area hazard. It is believed that ground cover would also show a significant correlation with future loss, because it is correlated with current loss which in turn is associated with future loss.

Stand volume per acre was already known to be significantly correlated with both current and future loss. Hence its correlation with current loss in this problem merely substantiates previous findings.

Tree vigor also showed a definite relationship with current loss in the present study, which substantiates the belief that current tree health, as expressed by the percentage of high risk volume in the stand, would prove valuable in prognosticating pine beetle hazard. This belief is further strengthened by the fact that in both this and Keen's 8/ studies susceptible volume per acre based on Keen tree classes showed a definite, though not significant, relationship with insect loss.

Although previously pointed out, the fact should be emphasized that a non-significant correlation in this study does not infer a definite lack of relationship between that factor and current insect loss. Certain factors were not sampled as planned in this study, so that their complete range was not represented. In addition, the sampling error in plots of this size is necessarily large, and the series of plots in this study is comparatively small. Had this study been carried out as planned, these difficulties would probably have been eliminated by a large series of plots.

However, the value in these independent studies of area hazard factors lies in the fact that each study brings out certain significant factors to be added to those known to correlate with insect loss. As data become available for analysis, future studies will test and perhaps find other factors which are important. On the basis of those known at the present time, it is believed that a multiple regression combining past loss, percent of high risk volume, volume per acre, ground cover and percent growth reduction would be found to explain a high percentage of the variation in future loss. To complete this analysis, it might prove interesting to include some measure of site and fire history, although in all probability both of these are well represented by the five factors already included above. One factor, that of soil, stands out as one which is important and should be included in such a study.

SUMMARY

The importance of knowing the factors which indicate the hazard of areas to western pine beetle attack is pointed out in this report and the progress of Salman and Johnson, and Keen and Grant in determining these factors is summarized and discussed as an introduction to the study herein reported.

The basis for the present study comprised 139 one-acre plots which were established and examined in 1939 by insect survey crews working in eastern Oregon and Washington.

In the analysis of these one-acre plot data, sixteen independent variables were correlated with mean annual insect loss expressed in percent of stand killed, and it was found that the amount of ground covered with brush showed a significant positive correlation with current loss; the amount of ground covered by reproduction multiplied by its average height showed a highly significant positive correlation with current loss; the stand volume per acre showed a highly significant negative correlation; and tree vigor showed a significant negative correlation.

The factor of brush was eliminated and the three remaining factors combined with current loss in a multiple regression which resulted in a highly significant multiple correlation coefficient which showed that about 21 percent of the variability in current loss was explained by these three factors. The factor of reproduction accounted for 43 percent of the explained variation and stand volume for about 35 percent.

In the light of other studies, this suggests that a multiple correlation combining past loss, percent of high risk volume, volume per acre, ground cover, and percent growth reduction would explain a high percentage of the variation in future loss.

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